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Art. XVI.—*The Geology and Petrology of the Mt. Leinster District, N.E. Victoria.*

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(With Plate X.)

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Introduction.

The name of the area under discussion is taken from the most important peak, Mt. Leinster (4,720 feet), which lies 11 miles to the E.N.E. of Benambra and 20 miles from Omeo. The area mapped comprises the major part of the Parish of Guttamurra, County of Benambra, together with small portions of neighbouring parishes. Mt. Leinster is a member of the Bowen Mountains which form the Main Divide in this part of Victoria; to the south-west the divide runs to Mt. Tambo, while to the east it passes out to the head waters of the Limestone Creek along a very low and poorly defined ridge.

The oldest rocks in the district are Upper Ordovician (?) sediments, which have been intruded by granodiorite, the intrusion of which has converted the sediments to mica schists and quartzites, and rendered its own border gneissic. A series of alkaline rocks has been extruded upon the eroded surface of the granodiorite and schists, and followed by intrusion of rocks belonging to the same series. The extrusive rocks are trachytes and trachytic tuffs, and syenite is the intrusive phase of the series. The intrusion of the syenite into the granodiorite has produced some very striking changes in the latter, notably the conversion of biotite to hornblende and finally to augite. A fault on the south-west spur of Mt. Leinster has brought the granodiorite and trachyte into contact, and a series of specimens across the shear zone is described.

A large area of granite porphyry on the south-west of the area occurs, but does not come into relation with any of the alkaline rocks. It is believed to be intermediate in age between the granodiorite and trachytic series. The whole area has been eroded, leaving the younger alkaline rocks standing as prominent peaks, and the sediments and granodiorite occuping the low-lying parts.

Previous References.

The earliest reference to Mt. Leinster is by A. W. Howitt (10), in which he says, "I am unable to assign an exact place to the interesting rock masses of Mt. Leinster, but, from a few microscopic sections that I have prepared. I conclude that they probably all belong to the class of 'porphyries'." In 1890 (13) he figures syenite porphyry (some of which appear from his figures to be trachytes) and quartz diorite (granodiorite) and gives an analysis of syenite porphyry, pointing out its high content of alkalies. He considers the syenite porphyry younger than the quartz diorite and a final stage of the intrusion of the granitic magma. He suggests the formation of gneisses from the quartz diorites "by the violent mechanical disturbances connected with the later eruptions of syenite porphyries through the older rocks." Dunn(6) mentions the occurrence, near the Mt. Leinster Station, of a complex of volcanic agglomerate intruded by numerous dykes. Skeats(15), who visited the area in company with Dunn, describes some of the rock types. He mentions solvsbergite as amongst the types present and that among the pyroclastic rocks the most abundant fragments are those of an alkaline rock with a trachytic texture, probably an alkaline trachyte. He also reconciles Howitt's petrographical work with a chemical analysis of the rock by pointing out that Howitt's orthoclase is really anorthoclase and that the augites are soda-rich types.*

Physiography.

The area mapped is drained by the Morass Creek and its tributaries, which flow through a broad open valley flanked in general by steep-sided hills of the younger igneous rocks, but in some parts by more gently sloping ridges of sedimentary and granitic rocks. The Morass Creek has two temporary base levels in the area. In both cases the stream meanders sluggishly through deposits of alluvium above a barrier of hard syenite, and below it is a fast-flowing stream with little or no alluvium. One of these barriers is a spur running N.W. from McFarlane's Lookout, and crossing the creek just outside the area mapped. Behind this barrier, it is possible, in some parts, to trace four or perhaps five alluvial levels which may be due to alternate dry and wet periods associated with glacial and interglacial periods in Pleistocene times. Only the more recent and more definite of these alluvial levels is shown on the map.

The second base level, at Mt. Leinster, is more striking physiographically. The Morass or Mt. Leinster Creek rises in the open undulating country of the Marengo flats, and flows northward and westward through a broad open valley until it reaches the northern extension of Mt. Leinster, where it has carved a deep, narrow gorge through syenite. A much easier course through softer sedimentary and gneissic rocks is available about a mile to the north; yet the stream has gone through

* Since the preparation of this paper, a reference to Mt. Leinster has been found in Vol. 7 of the Proc. Roy. Soc. S.A., 1885. A geological sketch section through the Australian Alps by James Stirling passes through Mt. Leinster, which is stated to consist of quartz porphyry of an intrusive character.

the harder syenite. It seems, therefore, that the stream was superimposed on the syenite, which would not be exposed when the level of the country was about 1,000 feet higher than at present.

Mapping.

Our aim in mapping was twofold, firstly, to map the geological boundaries with as much accuracy and detail as the exposures permitted, and secondly to produce a contour map of the area. The contours are based upon tacheometric surveys carried out with a theodolite and staff up the main ridges and creeks, supplemented by information obtained from geological mapping and pacing traverses. The height of Mt. Leinster was determined by the theodolite shots to neighbouring trig stations, Mt. Cobberas, Mt. Tambo, and Mt. Brothers. Sights were then taken to the more important points in the area, such as Little Leinster, McFarlane's Lookout, and Pendergast's Lookout. Little Leinster and McFarlane's Lookout, which are sharp-pointed peaks and visible from nearly all parts of the area, were used as referring marks to determine reduced levels in other parts. The tacheometric traverses were started from corners of allotments, with a sight to Little Leinster or McFarlane's Lookout, or both, if possible, to determine reduced levels. Wherever possible during these surveys check shots were taken to referring marks and the traverse closed on to a corner post or on to another survey.

Geological mapping was done by compass and chain with the clinometer for determining levels and corrections on steep slopes. These traverses were generally started from corner posts of known reduced level, but where these were not available, as on Mt. Leinster, from points fixed by theodolite work. These traverses were closed on to fixed points such as corner posts or other traverses, either theodolite or compass and chain, enabling errors to be adjusted out.

The mapping was done during two visits in the Christmas vacations of 1930 and 1931, giving a total time of four months in the field. The geological mapping was done by the authors, who are greatly indebted to the University students who carried out the topographical survey.

Petrology.

The rocks of the area are divisible into two groups:—

(*a*) An older series of sediments of Upper Ordovician (?) age which has been intruded by granitic rocks with the production of schists and gneisses, with more or less unaltered sediments in some parts—the Metamorphic Complex of Tattam(16).

(*b*) A younger series of alkaline rocks which has been deposited on the eroded surface of the metamorphic complex as lavas and tuffs, and intruded into it as hypabyssal and plutonic rocks.

Upper Ordovician (?).

These, when unaltered, consist of unfossiliferous alternating shales and sandstones. For information concerning the age of these rocks we are indebted to Mr. D. E. Thomas, B.Sc. Most graptolite localities in N.E. Victoria indicate an Upper Ordovician horizon, the nearest to Mt. Leinster being Wombat Creek, where T. S. Hall(7) has described species of *Diplograptus* and *Dicellograptus*. At Gibbo Creek(9), about 15 miles N.W. of Mt. Leinster, Upper Darriwil rocks outcrop on the crest on an anticline. Thus rocks belonging to the Darriwilian horizon do occur, but since the majority of the forms indicate an Upper Ordovician age, the rocks of the Mt. Leinster area are provisionally classed as the same age.

Practically unaltered sediments, which may, however, have been slightly altered by the intrusion of the syenite which forms the major part of Pendergast's Lookout, occur on the high ridge which runs east from the saddle on the east of Pendergast's Lookout. Elsewhere the sediments are altered, presumably by contact metamorphism with the underlying granodiorite and the orogenic pressure of its intrusion, into a series of mica schists and micaceous quartzites. The strike of the schistosity of these rocks is about 15° E. of N. Amongst the mica schists, the nodular cordierite schist described by Tattam(16) is represented; in this the cordierite is represented by a core of unoriented mica, surrounded by a ring of relatively clear pinite; these nodules have flakes of muscovite branching off at their side and merging into the mica base. Tattam describes the same kind of texture with branching chlorite instead of muscovite.

On the south-west spur of Mt. Leinster a thin layer of sedimentary material overlies an outcrop of non-foliated granodiorite. Injection has occurred in these rocks giving three types of which the first two differ only in the amount of injected material, which has been forced along the original bedding planes. In the first stage (specimen 2670),* the sedimentary material can be easily recognized as hornfels, into which magmatic material has been injected along the bedding planes. Since the sedimentary material is dark, and the magmatic material is white, the effect is striking. Under the microscope the former is seen to consist of quartz, felspar, and abundant sericite, and the latter of foliated quartz and felspar. In the

* Numbers in brackets are those of sections in the rock section collection in the Geological Department, University of Melbourne.

final stage of this injection, the sedimentary material is represented only by micaceous bands, and most of the rock consists of igneous material, consisting of quartz, plagioclase, orthoclase and microcline (section 2673). In specimen 2671, the rock appears to have less defined planes along which injection can take place, and the addition of magmatic material seems to have been more in the nature of absorption of magmatic solutions by a relatively porous rock. The hand specimen shows the igneous material throughout the sedimentary with no relation to any controlling structural direction in the original rocks. The section shows lenticles of felspar and quartz, which is frequently granulated, in a finer, granular matrix of sedimentary material, chiefly quartz. In all these rocks pressure effects are exhibited by undulose extinction and granulation of quartz, and the inversion of orthoclase to microcline. The action of magmatic liquids has in some cases partially or completely altered the femic material of the sediments to epidote; in section 2674 the only femic material is epidote, which forms veins through the rock.

In places, particularly on the south of Splitter's Creek, the granitic magma seems to have had a great amount of energy and wholesale injection of igneous material accompanied by strong metamorphism of the sediments has taken place. In some cases the latter become schists which in the hand specimen seem to consist of mica only. Besides the injected material, many pegmatitic and aplitic dykes and veins occur in the schists.

Granodiorite and Associated Gneisses.

The granodiorite occurs in three parts of the area, and, as it weathers easily, it usually forms low-lying country in which the only outcrops are in the beds of the creeks; this is the case in the central portion of the area and in the gently undulating country of the Marengo flats to the east of Mt. Leinster. On the other hand, the small outcrop to the south of Mt. Leinster stands out boldly with steep slopes, at a much higher level than the other two occurrences.

A typical specimen 2632, taken from Old Yard Creek, shows traces of alteration in the presence of fibrous green hornblende fringing biotite, and possibly the fringing with orthoclase and the veined antiperthitic structure of the plagioclase may be due to the intrusion of syenite. In hand specimen it is a holocrystalline rock with quartz, grey felspar, and flakes of black biotite. The minerals seen to be present in thin section are quartz, orthoclase, plagioclase, biotite, and hornblende, accessories being apatite and iron ore. The plagioclase is andesine, $Ab_{55}An_{45}$, and it is veined and bordered by orthoclase, an effect which may be due to the intrusion of the syenite. The biotite is strongly pleochroic, from light yellowish green to deep brown.

It is often fringed with green fibrous hornblende, which is purely a secondary alteration due to the syenite intrusion. A Rosiwal analysis gave the following proportions by weight of the minerals present:—

	Per cent.
Quartz	32.1
Plagioclase	40.6
Orthoclase	15.1
Biotite	7.2
Hornblende	5.2
	100.0

These figures agree fairly well with the norm, and show that the rock is a granodiorite, since the proportion of orthoclase is less than a third of the total felspar present.

The granodiorite has undergone attack from solutions in many places. The mineralogical effects due to these are the formation of epidote, sericitization of the felspars, conversion of biotite to penninite, the formation of clinochlore from hornblende, an increase in the amounts of apatite and iron ore, and the introduction of pyrite. All these effects, except the latter, are well seen in section 2582. The changes may either be due to solutions coming from the syenite magma, or may be an end phase of the intrusion of the granitic magma itself.

Relations with Older Rocks.

The intrusion of the granodiorite, according to Tattam(16) has taken place during a period of great orogenic pressure: " Igneous intrusion was directly connected with folding, lateral pressure squeezing up the magma from some underlying reservoir." Shearing took place along the contact of the magma with the intruded rock with the production of schists and gneisses, which " have been formed from both sedimentary strata and igneous material by processes of injection and assimilation at high temperatures. Piezo crystallization, that is, crystallization of a viscous and constrained magma during the operation of powerful directed pressure, best explains the phenomena. Pressure was due to the opposing forces of magmatic intrusion and orogenic forces. When orogenic pressure was spent the granite consolidated as a non-foliated rock with non-schistose contact rocks." In this area the granodiorite has a gneissic border of varying width depending on the stage at which orogenic pressure was spent. As this contact is approached, the development of a parallel arrangement of the biotite flakes is accompanied by the appearance of muscovite and the sericitization of the felspars. Finally the muscovite becomes equally, if not more important than the biotite.

Close to the junction with the schists, patches of andalusite, cordierite, and quartz occur in the igneous rock (2581), representing remnants of sedimentary material which has not been fully digested. A gneiss containing sillimanite (2583) has many features which Tattam (6) has described as occurring in the metamorphic rocks of north-east Victoria. In this rock the sillimanite is associated with muscovite from which it has developed; sillimanite rods are also enclosed in quartz. Quartz is abundant, orthoclase is present as clear crystals, with striations due to inclusions of another mineral along one of its cleavages, the plagioclase is highly sericitized in the centre of the crystals, the more sodic part on the outside being more or less untouched. Myrmekite occurs at the contact between orthoclase and plagioclase crystals and encroaches on the orthoclase in the manner described by Sederholm (14) (Pl. X., Fig. 2). This occurrence of myrmekite is accompanied by an intergrowth of white mica and vermicular quartz, usually at the end of the mica flakes. The biotite, which is present in proportions roughly equal to that of the muscovite, is partly chloritized, this process being accompanied by the separation of iron ore. Tattam (16) does not record any development of sillimanite from muscovite, but a similar effect, the fibrolitization of biotite, he considers to be due to "differences in dynamic physical equilibrium in different parts of the rock," involving a migration of chemical compounds.

Relations with Syenite.

The granodiorite and syenite come into contact on the east face of Mt. Leinster, above the Marengo flats, the syenite being intrusive into the granodiorite. Good exposures of the contact occur on these very steep slopes, and at one spot a series of specimens was collected across it. In the hand specimens the most striking change is the disappearance of quartz from the granodiorite as the contact is approached, the rock coming to resemble a diorite, with felspar and hornblende visible. This rock can easily be distinguished from the syenite, which has a characteristic pink colour.

The syenite is more or less normal up to the contact. At the contact augite is present, which, on moving away from the contact, gradually passes into hornblende until only hornblende is left. Also a few grains of quartz appear away from the contact. These changes indicate a more rapid crystallization of the syenite at its margin than in the body of the magma, due to chilling and the loss of mineralizers, which the following description shows to have migrated into the granodiorite.

The changes in the granodiorite as the contact is approached consist of an increase in the amount of potash felspar, largely at the expense of the quartz, and the inversion of the ferromagnesian minerals to higher-temperature forms, with the consequent absorption of quartz. Even at some distance, about a quarter of a mile, from the contact, the plagioclase is fringed with orthoclase and veined by it in a most intricate manner. This, however, may be due to processes acting in the late stages of crystallization of the granodiorite itself. Nearer the contact the quartz becomes corroded, and forms intergrowths with orthoclase. The quartz of the intergrowths is clearly derived from the original quartz crystals, since the two are in optical continuity. As the contact is approached, more and more quartz is corroded, until finally most of the quartz has been affected. The intergrowth then gradually disappears, and finally only orthoclase remains. A series of Rosiwal analyses, made of the sections, show that the sum of orthoclase, quartz, and intergrowth is fairly constant, indicating that the orthoclase replaced the quartz as the latter was dissolved. This implied that orthoclase was the stable, and quartz the unstable phase in the solid state.

The quartz of the original granodiorite is also involved in the solution of the biotite and the reaction of this solution with quartz to form hornblende. This hornblende, which is a green fibrous variety, borders the quartz or traverses cracks in it. Sometimes it surrounds the biotite. The biotite in this series exists in two forms. The original biotite of the granodiorite has a reddish tinge, which Howell Williams(17) has shown to be due to reheating, and shows a fringe of hornblende. The other form is normal greenish-brown biotite, which has formed during the subsequent re-cooling of the rock. The first form becomes more and more replaced by secondary hornblende as the contact is approached, until it is practically all gone. At the contact itself augite appears(2587) in well-formed crystals, in contrast to the somewhat fibrous hornblende; in some cases the augite crystals almost encircle patches of fibrous hornblende, showing the inversion relations between the two. This augite has again partly inverted to biotite, which is probably due to the combined effect of re-cooling and the action of alkaline liquids derived from the syenite magma. The reaction is essentially biotite + quartz $\rightarrow$ hornblende in the presence of alkaline liquids. The temperature induced by the intrusion of the syenite favours the formation of hornblende. As hornblende fringes both quartz and biotite, both of these minerals must have gone partly into solution. In each case solution has been caused by mineralizers which have been introduced into the granodiorite by the syenite magma. Solution of quartz has taken place with the concomitant deposition of orthoclase which was in solution in the liquids, the heat of crystallization of the orthoclase assisting in the solution of the quartz, as described by Bowen(4) :—"Later members (of a reaction series) can become part of the liquid by a sort of reactive solution, the heat of solution . . . being supplied by the precipitation of their heat equivalent of members of the series with which the liquid is saturated." This would account for the intergrowth of quartz and orthoclase mentioned previously. A similar phenomenon has occurred in the case of biotite, original biotite being replaced by a mixture of iron ore and orthoclase.

In section 2591 the plagioclases have broken down into a fine grained aggregate of felspar crystals. In this change the crystals of plagioclase first become traversed by mesh-like veins of quartz and then small individual plagioclase crystals form from the big one, increasing in number until finally no trace of the original crystal remains. This effect is probably due to local shearing, perhaps acting contemporaneously with the intrusion of the syenite magma. Since the other minerals, quartz and the ferro-magnesians, were unstable at this time, pressure on these could be relieved by solution, and not by the breaking down of the crystals.

In a section 2594 taken from a specimen collected about half a mile south of those described above, biotite, hornblende, and augite are present. The hornblende is very abundant around the edges of quartz crystals and in particular where biotite adjoins the quartz. The augite has been developed from the hornblende, with which it is associated. The biotite is corroded. It is an instance of the solution of biotite and reaction with quartz to form hornblende, and on further heating the inversion of hornblende to augite.

Granite Porphyry.

The granite porphyry occurs in the high hills which rise in the south-western part of the area, with steep slopes and forming many large outcrops. The typical specimen 2595 is taken from the northern slopes of these hills. The hand specimen shows clear vitreous quartz crystals, with larger white felspars about 1 cm. in length, and black specks of biotite, in a fine light-brown groundmass. In thin section there are phenocrysts of quartz, felspar, and biotite. The felspars consist of perthites and oligoclase $Ab_{85}An_{15}$. The groundmass consists of quartz and felspar. A Rosiwal analysis of the section gave the following proportions of the minerals as phenocrysts and groundmass:—

		Per cent.
Phenocrysts—	Quartz	24.8
	Orthoclase	12.5
	Plagioclase	8.0
	Biotite	4.1
Groundmass—	Quartz	16.1
	Felspar	34.5
		100.0

Using these figures in conjunction with the chemical analysis, the composition of the felspar in the groundmass was calculated to be about Ab_1Or_1, with a little anorthite. This result, however, is approximate, since the potash felspars appear to contain some of the albite molecule, and vice versa.

The plagioclases in the perthites are blebs arranged parallel to (100), and are comparable to Alling's(1) vein type, which he considers to be of deuteric origin.

The rocks in this series show a wide variation in texture, from a porphyritic pitchstone (2596) to rocks which have almost a granitic texture (2597). The mineralogical content remains practically the same, with quartz, perthite, acid plagioclase, and biotite; sometimes, however, the composition seems to become more sodic and the proportion of the plagioclase increases.

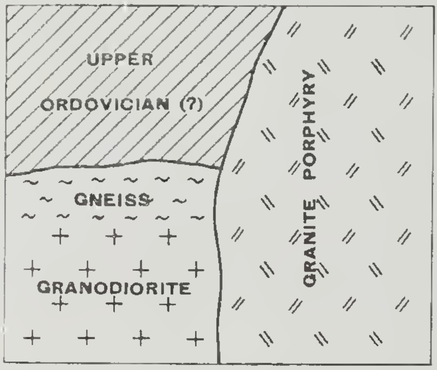

Fig. 1.—Sketch map showing granite porphyry cutting across the gneissic contact of granodiorite with Upper Ordovician sediments. These relations occur just outside the south-west corner of the area.

Specimen 2598 is interesting in that it has a granophyric texture in which quartz occurs in optical continuity throughout the entire rock, which consists mainly of orthoclase with a smaller amount of plagioclase. Although some of the orthoclase crystals are larger than usual, there is no definite groundmass in this rock.

Relations with Older Rocks.

The granite porphyry shows a transgressive contact with the Upper Ordovician sediments, thus being intrusive into them.

Fig. 1 shows the relations exhibited just outside the area on the south-west side. The granite porphyry successively cuts across sediments, the gneissic border of the granodiorite, and finally the normal granodiorite. This indicates an intrusive contact, and shows that the granite porphyry is younger than the granodiorite.

Age.

In this area there is no evidence of the age of the granite porphyry or of its relations to the syenite and trachytes. Howitt(11) has described "trappean rocks," which appear to be similar to the granite porphyry, and states that they intrude the granites, and that their age is Upper Silurian or Lower Devonian.

Trachyte—Pyroclastic Series.

These are a mixed series of lavas and tuffs, which in part become hypabyssal. With the exception of Pyroclastic Hill, they occur as hard metamorphic shells surrounding the syenite. In the hand specimen the trachytes have a fine-grained groundmass, and white or pink idiomorphic felspar. When unaltered the groundmass is brown to almost white, but it becomes a dark greenish-grey when metamorphosed. In thin section there are phenocrysts of felspar, augite, and magnetite with some small amounts of quartz in a trachytic groundmass of lath-shaped felspars, which are probably anorthoclases. The felspar phenocrysts vary in composition, ranging from typical orthoclase, anorthoclase, and microperthite with typical cross-hatched twinning, to plagioclase (oligoclase) with true lamellar twinning; the refractive indices vary accordingly from 1.520 to 1.535. Often several of the felspar phenocrysts are clotted together, giving a glomero-porphyritic texture. The ferro-magnesian minerals in the trachytes are nearly always badly weathered, and the original mineral can be identified only in a few cases. Augite has been recognized in three or four instances, but only one crystal of olivine was identified, and the alteration products suggest that augite is more common.

The pyroclastics alternate with the trachytes, and often it is difficult to distinguish between the two, as both have usually undergone a certain amount of metamorphism. Sometimes, evidently at or close to the centres of eruption, the fragments are very large, up to a foot in diameter. This occurs on Pyroclastic Hill, and again on the south side of the south-west spur coming from Mt. Leinster. At two places, where the trachytic material has broken through granodiorite, an agglomerate was formed consisting chiefly of granodiorite boulders, and it becomes difficult to distinguish the agglomerate of granodiorite fragments from a shatter zone in the trachyte into which the granodiorite has forced its way.

The hand specimen of the tuffs shows angular fragmentary material embedded in a dark greenish-grey base. The fragments are conspicuous on a weathered face, as they are generally harder than the matrix. The fragments are chiefly trachyte, some being relatively coarse, and others are probably devitrified glasses. On Mt. Leinster there are fragments of monzonite-porphyry and granodiorite, and on Pendergast's Lookout there are sedimentary fragments. Fragmentary felspar, perthites, and plagioclases occur at both these places. Sometimes the fragments are embedded in an almost vitreous base (2613) which shows a certain amount of flow structure under the microscope, possibly representing a volcanic mud flow.

Relations with Granodiorite.

The occurrence of fragments of granodiorite in the tuffs indicates that its trachytic series is younger than the granodiorite. In the bed of Mac's Creek, and on the east slopes of Mt. Leinster, above the Marengo flats, agglomerates have been formed consisting chiefly of large granodiorite fragments, up to a foot in diameter. These evidently represent centres of eruption.

On the north side of the Mole Hill, the mapping seems to indicate that the trachytic rocks lie on the eroded surface of the granodiorite and schists, but not much reliance can be placed on the mapping at this place, since the exposures were very poor.

About a quarter of a mile somewhat W. of S. from the top of Mt. Leinster, a fault brings the granodiorite and trachyte into contact. This was not recognized as a fault junction in the field, but it is proved in the microscopic evidence of a series of specimens (2599-2606) taken across the junction. The shear zone is about 20 feet wide; the changes observed in the granodiorite are the breaking up of the quartz into a mosaic, and the replacement of the felspars by a fine felspathic groundmass. This latter is more conspicuous as the shear zone is entered, the groundmass forming along the cracks in the felspar, until finally only a ghost, formed probably of kaolinized material, remains of the felspar. The unaltered felspars show hardly any strain polarization, indicating that the stresses have been relieved purely by the breaking down of the minerals. A similar process has been described by Wiseman(18) in granulitized granites from East Greenland.

The breaking down of the felspars also takes place in the trachytes. The original ferro-magnesian minerals in both rocks have been converted to secondary hornblende and biotite, and epidote and calcite occur, appearing to have been deposited from solution. In one case an intergrowth of orthoclase and somewhat vermicular quartz occurs in the trachyte. The relations are complicated by the proximity of intruded syenite and the characteristic contact metamorphism in both granodiorite and trachyte.

In another place, not far from the above, the rock shows evidence of the passage of solutions between trachyte fragments. These solution tracks have a fine felspathic matrix, and contain epidote, zoisite, chlorite, calcite, albite, apatite, and sphene. These minerals most probably have an ultimate magmatic origin, and it is suggested that the faulting occurred contemporaneously with the intrusion of the syenite.

Relations with Syenite.

The trachyte and syenite are obviously co-magmatic, since at a chilled contact of syenite and trachyte, it is frequently very hard to decide, even under the microscope, where the chilled syenite stops and the trachyte begins. Syenitic dykes and veins cut the trachytic series, and mineral changes can be traced in them as the contact with the syenite is approached, showing that it is an intrusive contact. One single piece of syenite was found in the tuffs on the Mole Hill: this is taken as evidence that the late stages of volcanic activity continued into the early stages of the intrusion of the syenite.

Distinct mineralogical changes occur in both the trachytes and pyroclastics on approaching the contact with the syenite. The changes are more pronounced in the pyroclastics, since the tufaceous fragments were not in chemical equilibrium at the time of their deposition, such as a volcanic rock would be at solidification. In their more advanced metamorphic stages the various fragments merge into a uniform base, and it becomes impossible to distinguish them from the trachytes. In a series of specimens (2607–2615) between Little Leinster to Mt. Leinster, it is observed that the metamorphism of Little Leinster is slight, and it becomes less in the saddle between the two peaks, but is rather marked on the face of Mt. Leinster above the saddle. In these specimens the most noticeable change occurs in the ferro-magnesian constituents—the heating of the trachytes by the syenite liberated iron ore from these minerals. This change is most common in biotite, which, taking into account the absence of biotite in the unmetamorphosed rocks, indicates that the separation of iron ore took place after the original mineral had inverted to biotite. It also, however, occurs in augite and hornblende. The biotite, however, may be an original pyroclastic mineral. The iron ore is seen to separate all through the original mineral, thus rendering it opaque, or along the cleavage planes, producing a more or less regular pattern. The same effect was described by Howell Williams (17) with artificial heating of andesite at Marysville Buttes, California. The separation of iron ore in the minerals of the trachyte was accompanied by the solution of the excess material and the deposition of clear felspar, so that the final product is a skeleton-like arrangement of iron ore mixed with small clear crystals of felspar (Pl. X., fig. 3).

The pyroclastics within about 20 feet of the contact of syenite exhibit an interesting set of reactions. Section 2614 contains clear pale green augite, which usually has a reaction rim about 0.1 mm. wide consisting of clear felspar, with some apatite. Sometimes, however, the augite is inverting to hornblende, which is pleochroic from yellowish-green to greenish-brown. The felspars consist of anorthoclase and plagioclase, the plagioclases being veined with potash felspar, and the anorthoclase fringed with secondary hornblende. This hornblende has crystallized all through the base, with some secondary biotite. Apatite occurs in quite large crystals; smaller ones occur with the ferro-magnesian minerals, but the larger ones do not appear to have any such connexion. Zoisite is present. The exact reactions which have produced these changes, in a fragmental rock such as this, would be very hard to trace, but in general seem to have been an interchange of salic and femic material in solution, as well as the introduction of material from the syenite. The reactions seem to have been the solution of augite with the deposition of felspar and apatite, and the reaction of this femic material, in solution, with anorthoclase to form hornblende. The fact that augite sometimes takes part in this reaction, and sometimes undergoes a simple inversion to hornblende, may be due to a different composition of the matrix with which it is in contact, giving a different set of equilibrium conditions. In the hand specimen of 2615 which is just at the contact, hornblende crystals up to 1 cm. in length are visible. Under the microscope these are seen to have a core of augite. In addition to the big crystals of hornblendes, secondary hornblende has crystallized throughout the groundmass with some biotite. Comparatively large crystals of apatite are present. The rock is traversed by small veins less than a millimetre in thickness, and very irregular in their composition, which apparently depends on the composition of the base through which they pass. Felspar, calcite and uralite are the main constituents of these veins.

Age of Trachytic Series.

The only evidence occurring in the area concerning the age of the trachytic rocks is of such an obscure nature that the authors do not place much reliance upon it. On the east side, almost at the foot of the Mole Hill, there occurs, just at the foot of the tufaceous series, a big boulder of conglomerate. This boulder is about 3 feet square, and is embedded in soil. It is an entire stranger to this district, and bears a strong lithological resemblance to the Mt. Tambo conglomerate, which outcrops about 7 miles away. Howitt(12) has shown this series to be Upper Devonian in age. Whether the boulder is an ejected block, or the tuffs rest on it, the series to which it belongs, presumably the Mt. Tambo series, must be older than the tuffs. This would indicate that the age of the trachytic series is post Upper Devonian.

Soda Syenite.

All the prominent peaks in the district consist of syenite. The rock weathers easily, and most of the loose boulders are very rotten. The bold relief of the peaks is due to the hard metamorphic shell of trachyte which preserves the steep slopes; it is also due to the wide spacing of the jointing, which on the whole is poorly developed. The vertical jointing tends to produce steep cliffs, such as McFarlane's Lookout, where there is a cliff 500 feet high, and smaller ones on the west face of Pendergast's Lookout on the east face of Mt. Leinster.

The typical specimen of syenite (2616) is taken from the western extremity of a ridge which lies about a mile in a direction E.S.E. from McFarlane's Lookout. In the hand specimen the rock has a coarse even-grained texture, with grey felspars and black ferro-magnesian minerals. In thin section the felspars are microperthitic, the crystals having an average length of about 4 mm., and ranging up to 6 mm. The ferro-magnesian minerals are pale green augite, which is surrounded by hornblende; the hornblende is pleochroic in browns and greens. There are also flakes of biotite present. Accessories are apatite, sphene, and magnetite; the latter usually being associated with the ferro-magnesian minerals. A Rosiwal analysis gave the following proportions by weight of the minerals present:—

	Per cent.
Micro-perthite	90.9
Hornblende	5.6
Augite	1.3
Magnetite	1.9
Sphene	0.3
Apatite	tr.
Quartz	tr.
	100.0

The chemical analysis of the soda syenite shows a close similarity to that of a pulaskite from the Fourche Mts., Arkansas. Since there is also a close agreement in the mineralogical content, the rock may be called a pulaskite; the specimens with considerable amounts of quartz grading into the nordmarkite type.

A peculiar feature is the interpenetrating texture of the felspars. This texture will be considered later in connexion with a dyke in which this texture shows its best development.

There is a wide variation in the grain size of these rocks, and pockets occur as on McFarlane's Lookout in which the felspar crystals are much larger than normal; these probably represent the final crystallization products of the magma from an almost aqueous solution. On McFarlane's Lookout the typical syenite contains hardly any quartz, but in other parts the proportion of quartz increases until, in some specimens on Pendergast's Lookout, the quartz forms about one-third of the whole rock (section 2617). In other sections (2619, 2620) quartz becomes abundant, but only as interstitial material.

The normative felspar, as calculated from the chemical analysis, is $Ab_{51}An_{11}Or_{38}$ and considering the high percentage of felspar present, this should be very near the true composition of the felspar. In the typical specimen, the felspar is a very fine microperthite, with the two felspar components forming a very fine mesh-like structure, in which the individual felspars are indistinguishable. In other specimens the coarseness of the perthites increases, and the lamellar twining of the plagioclase can be easily distinguished. This change in the texture of the perthites often seems to be accompanied by an increase in the amount of quartz in the rock (2625, 2626), and may be associated with a lower temperature of crystallization. In these coarser types the plagioclase can be seen to occur as films, which are arranged roughly parallel to the (100) plane of the host felspar, and are comparable to the film type of perthite, as described by Alling(1), and which Anderson(2) assigns to ex-solution. Sometimes the perthitic structure is absent in the felspars. These are probably anorthoclases which have cooled more rapidly than the perthites. Sometimes soda-rich plagioclase has crystallized out, and is accompanied by an increase of quartz in the rock (2618). This plagioclase is somewhat anti-perthitic.

The ferro-magnesian minerals are typically soda-rich forms; pale green augite, aegirine-augite, and aegirine are the pyroxenes, with green, brown, and sometimes blue hornblende, and biotite. The pyroxenes and amphiboles are strongly zoned, showing an increasing soda content in the successive outer zones of the crystals. Pale green augite is frequently surrounded by a rim of aegirine-augite or aegirine, and brown or green hornblende may have crystallized around it. The latter frequently has a rim of blue hornblende around it. Biotite occurs as odd flakes in any of the above. The occurrence of these minerals is very sporadic, sections which have been cut from the same specimen not having the same mineral content.

Interesting changes occur in the syenite when it becomes chilled against the intruded rock. The ordinary crystals occur as phenocrysts, with a fine groundmass which in most cases is very siliceous. The quartz in the groundmass may originate in three ways—by marginal assimilation of quartz in the crystallizing magma; by secondary enrichment of the groundmass in quartz; or thirdly, it may represent an earlier more siliceous phase of the intruding magma. The first explanation is indicated in section 2629, where corroded quartz crystals and a siliceous groundmass occur just on the junction between mica-schists and syenite. Secondary quartz, which has crystallized in the interstices of the felspar crystals, is also common, and arises from circulating siliceous solutions during the final stages of crystallization. In the third alternative the supposition of an earlier acid magma is in accordance with the views of both Bowen(3) and Daly(5), who state that a syenitic magma can be derived from a granitic magma. In the chilled border the syenitic minerals occur as phenocrysts with the quartz in the groundmass, so that the formation of a syenite would be accomplished by the squeezing out of the residual siliceous liquid by earth movements, as suggested by Harker(8), leaving only the syenitic minerals. The granophyric dyke rocks may represent the residual liquid which has been squeezed out. This derivation would be a modification of Bowen's hypothesis, which is the sinking of quartz crystals or the squeezing out of the syenitic magma from the partly crystallized granitic magma. Daly, on the other hand, claims that the assimiliation of limestone or basic sediments is the major factor in the derivation of a syenitic magma. Although no limestone now occurs in the area, it does occur in many places in the surrounding district, such as Buchan, Bindi, and the Limestone Creek. The syenite on McFarlane's Lookout rises 1,000 feet above the intruded mica schist, and it is quite possible that limestone was present there during the intrusion of the syenite. The mica schists are all acid types, so that the hypothetical limestone or basic sediments would be necessary to explain the derivation of the syenite on Daly's hypothesis.

In places the chilled border phase of the syenite can be seen to be broken up and veined by coarser syenitic material, showing that a chilled border phase was formed, and then reintruded at a later stage of the intrusion.

Dyke Rocks.

The dyke rocks of this area comprise a number of interesting types. The most basic types are lamprophyres, of the spessartite type. Most of these contain phenocrysts of labradorite, and the felspars in the groundmass, when recognizable, are seen to be oligoclase or andesine. Hornblende and augite are the two ferro-magnesian minerals originally present. Hornblende is practically the only ferro-magnesian mineral in sections 2640 and 2641. Specimen 2642 forms a large dyke in the extreme east of the area, and specimens of it were collected by Professor Skeats when he was passing through the area in 1906. It is a hornblende porphyrite, and consists of large crystals of hornblende, which have been largely converted to chlorite, epidote, zoisite, and quartz. The felspar occurs as small crystals in the groundmass, consisting mainly of plagioclase, $Ab_{65}An_{35}$. This is the only section in which porphyritic crystals of felspar do not occur. In the other sections examined, augite has remained practically unaltered, but the hornblende has been entirely replaced by epidote, zoisite, calcite, and chlorite, the last of which is most abundant, and often retains the original shape of the hornblende. In section 2633 the hornblende is represented by quartz, calcite, and chlorite, but the original shape of the hornblende has been retained. The calcite, chlorite, and quartz are segregated in separate areas inside the original hornblende crystal. In other rocks, the hornblende is present only as rods in the groundmass, and the augite occurs as crystals having a granulated appearance.

Many of the dykes clearly show a derivation from the syenite magma and form a continuous series between monzonite porphyry at one end to granophyre at the other. The monzonite porphyry has phenocrysts of oligoclase to andesine which are often bordered by anorthoclase in a coarsely trachytic groundmass of anorthoclase laths, with interstitial quartz in a few cases. Fragments of these rocks are found in the tuffs, showing them to be an early dyke phase. As the phenocrysts become more and more sodic, and finally become anorthoclase, the rocks grade into the solvsbergite type. These have phenocrysts in a coarse trachytic groundmass of anorthoclase laths. The ferromagnesian minerals are generally badly weathered and cannot be determined.

The coarse trachytic texture of the solvsbergite grades into an orthophyric one; in some sections the two textures are seen existing side by side (2652), and in others the orthophyric is imposed on the trachytic, giving a peculiar mottled effect to the felspar laths in the section (2654). Where the texture is entirely orthophyric the rock becomes an orthophyre (2655), consisting of phenocrysts of anorthoclase in an orthophyric groundmass of short stumpy anorthoclase crystals. The ferromagnesian minerals are soda-rich hornblende and biotite, with magnetite and sphene as accessories.

As the rocks become more acid, interstitial quartz makes its appearance (2656), and as the amount increases it takes on a granophyric texture, the rocks finally becoming granophyres (2658). These are even textured, fairly fine-grained rocks, with occasional phenocrysts of anorthoclase, and a base of somewhat rectangular crystals of the same mineral, through which quartz has crystallized, giving a granophyric texture. Section (2660) is a granophyre of a different type, and does not fit into the series outlined above. It consists of phenocrysts of quartz, anorthoclase and micropegmatite, the latter also occurring as veins passing around the edges of crystals of the first two minerals. This micropegmatite makes up about half the rock, and gives some wonderfully intricate intergrowth patterns. The ferro-magnesian minerals are now represented only by clusters of iron ore minerals, with traces of chloritic material. Sphene is a common accessory mineral.

Glassy dyke rocks occur, which are often spherulitic. These may be called keratophyres, simply on account of the fact that they occur in a soda-trachytic series.

On the southerly spur on the west side of Pendergast's Lookout, a tinguaite porphyry dyke (2663) occurs along the junction of the trachytic series and the syenite, showing it to be younger than the syenite. In the hand specimen it is a fine-grained greenish grey rock, with flesh-coloured felspar phenocrysts. In section the felspars are seen to have cores of oligoclase-andesine, bordered by anorthoclase with typical cross-hatches twinning. The groundmass is very fine, and consists of matted needles of aegirine, with felspar laths and nepheline needles.

A dyke occurring on the south-east side of Pendergast's Lookout and passing up to the first hump of the ridge which runs south from the top of this peak, consists of a very interesting rock. It exhibits the best development of the interpenetrating texture of the felspar which is found in many of the syenites (Pl. X., Fig. 1). In the hand specimen it is similar to a quartz-free syenite, with white felspars and black hornblende. In sections (2664–6) the felspars are seen to be very fine micro-perthites, consisting of a fine network of two felspars, which, however, cannot be distinguished from each other. The ferro-magnesian minerals are brownish-green soda-hornblende, and biotite, the latter being subordinate and intimately associated with the hornblende. The pecular feature of these rocks is the interpenetrating texture of the perthites which occurs at the edge of two crystals; giving in section, patches of felspar which are in optical continuity with one of the crystals, throughout the adjoining ones. Sometimes this occurs to such an extent that a texture analogous to graphic granite is obtained, with one felspar crystallizing throughout the other.

The texture described has much the same appearance as a eutectic, and an explanation is advanced on this basis. The texture occurs only with the type of felspar described above, a very fine micro-perthite, the interpenetrating crystals being apparently of the same composition. Since these felspars are perthites, they can be considered as having crystallized in a system which included the albite-orthoclase system. The equilibrium diagram is taken to be of the form shown in Fig. 2, which is that given by many writers. On cooling, one or other of the components would crystallize out, till the eutectic temperature T_e was reached. The remaining liquid of composition E could then crystallize out as a eutectic mixture of felspars of composition L and M. This would give a eutectic intergrowth of the felspars. On cooling, each of the felspars would, by exsolution, form perthites, in the manner described by Alling(1).

At a temperature T, for instance, each set of felspars would consists of felspars of composition O and P, in the ratios $\frac{LP}{OL}$ and $\frac{MP}{OM}$ respectively. By this means, an intergrowth of perthites would be obtained, agreeing with the texture which has been described. Unfortunately, the perthites are so fine that the relative amounts of the two felspars in them cannot be counted, and so the relative amounts of the two phases cannot be determined, nor can the amounts of albite and orthoclase in each phase be found. In the main mass of the syenites this texture is rather sporadic, suggesting that there were pockets in which the residual eutectic liquid crystallized.

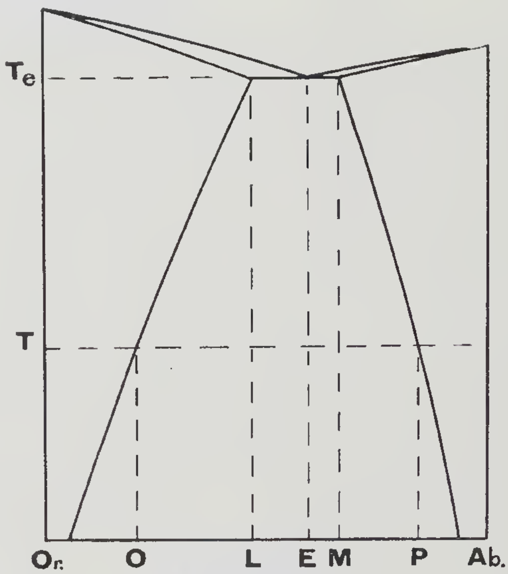

Fig. 2.—Qualitative thermal diagram showing the probable conditions under which the orthoclase-albite system crystallized in this area.

Acknowledgments.

In conclusion, we wish to acknowledge our indebtedness to Professor Skeats for suggesting the carrying out of this work, and for accompanying us on our first visit to the area; to Dr. Summers for valuable assistance in the petrological work, to Dr. Stillwell for assistance in the preparation of the paper, and to the staff of the Geology School; to Mr. Ampt for instruction in chemical analyses; to Mr. Darwin, of the Engineering School, for the loan of surveying instruments; and to Messrs. Barclay, White, Hosking, Moss, Cadwallader, Harvey, and Slatter for carrying out the topographical survey and assisting in the geological mapping.

TABLE OF ANALYSES.

—	I.	II.	III.	IV.
SiO_2	61.33	61.03	67.71	75.50
Al_2O_3	17.97	20.76	14.80	13.10
Fe_2O_3	5.99	4.01	2.63	2.12
FeO	0.44	0.75	3.06	0.29
MgO	0.60	0.80	1.30	0.16
CaO	2.23	2.62	3.59	0.53
Na_2O	5.00	5.96	2.68	2.83
K_2O	5.07	5.48	3.20	5.25
H_2O	0.84	0.59	0.69	0.83
TiO_2	0.42	..	0.33	0.25
P_2O_5	tr.	0.07	nil	nil
MnO	0.05	..	0.02	0.01
Total	99.94	101.07	100.01	100.87

TABLE OF NORMS.

—	I.	II.	III.	IV.
Quartz	7.5	..	29.0	38.0
Orthoclase	30.0	36.1	18.9	30.6
Albite	42.4	42.4	22.5	23.6
Anorthite :	11.1	9.2	17.8	2.8
Nepheline	..	2.3	..	..
Corundum	0.2	..	0.4	1.8
Hypersthene	1.6	..	6.3	0.4
Olivine	..	1.4	..	..
Magnetite	..	2.3	3.7	0.5
Hematite	6.1	2.4	..	1.8

I. Soda Syenite (Pulaskite) (Pulaskose, 1, 5, 2, 3). McFarlane's Lookout, Mt. Leinster District. Anal. E.B.

II. Pulaskite, Fourche Mts., Arkansas. (J. F. Williams). Anal. R. N. Brackett.

III. Granodiorite (Amiatose, 1, 4, 3, 3). Mt. Leinster. Anal. E.B.

IV. Granite Porphyry (Alaskase, 1, 3, 1, 3). The Gap, Mt. Leinster District. Anal. E.B.

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Explanation of Plate X.

Fig. 1. Section 2665. Dyke rock occurring on the south-east of Pendergast's Lookout. Showing the interpenetrating texture of the perthites. (x 15.)

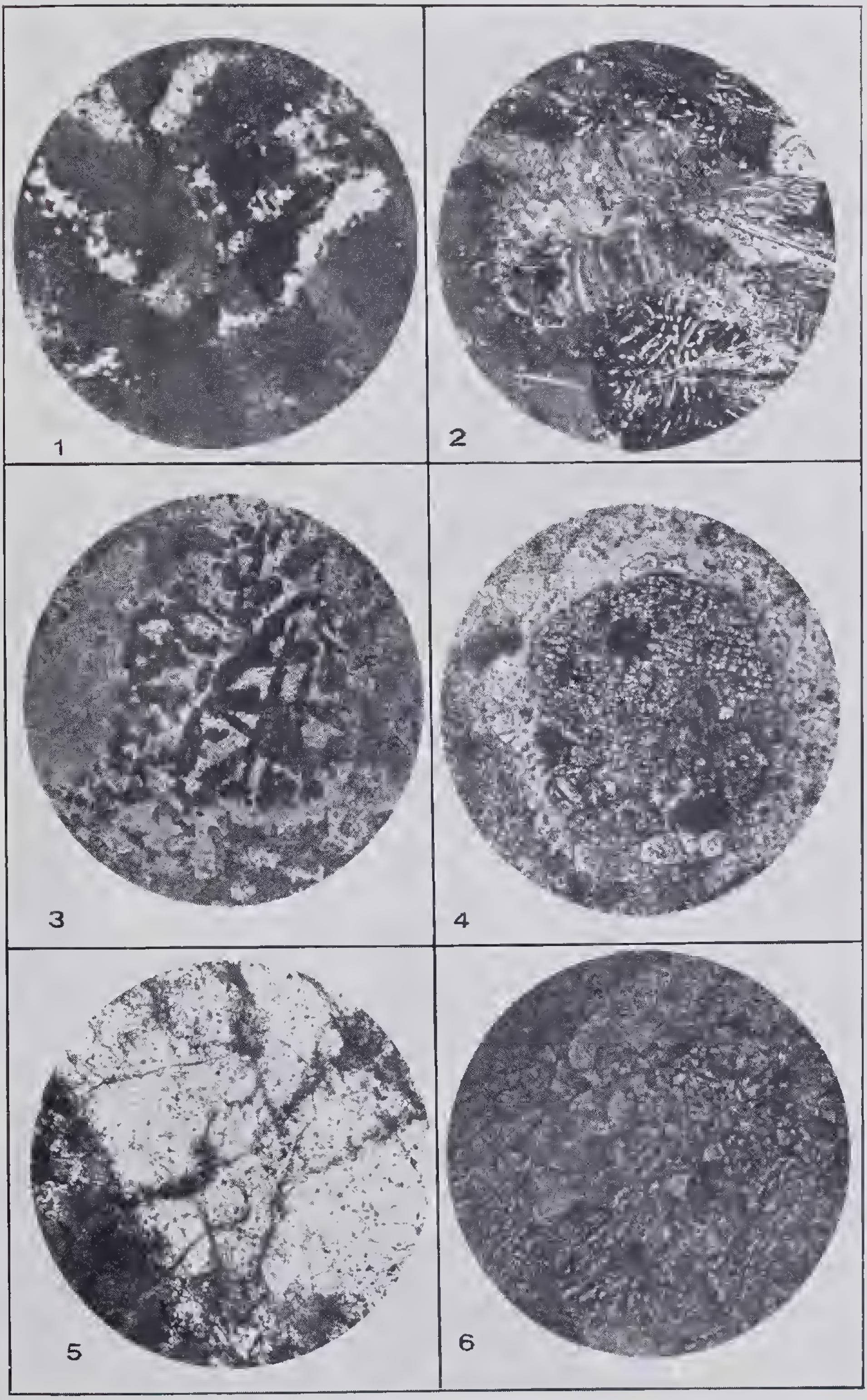
Fig. 2. Section 2583. Sillimanite Gneiss. Myrmekitic intergrowth of plagioclase and quartz. In the left hand bottom corner it is seen encroaching on striated orthoclase. (x 48.)

Fig. 3. Section 2614. Mosaic of iron ore and felspar, derived from ferromagnesian mineral, in metamorphosed tuff. (x 48.)

Fig. 4. Section 2614. Augite in metamorphosed tuff, with reaction zone of clear felspar, and apatite crystals around its margin. (x 48.)

Fig. 5. Section 2589. Granodiorite metamorphosed by syenite. Fibrous hornblende fringing and traversing cracks in the quartz. (x 48.)

Fig. 6. Section 2589. Granodiorite metamorphosed by syenite. Intergrowth of quartz (light) and felspar (dark) formed by solution of the quartz and deposition of the felspar. (x 48.)



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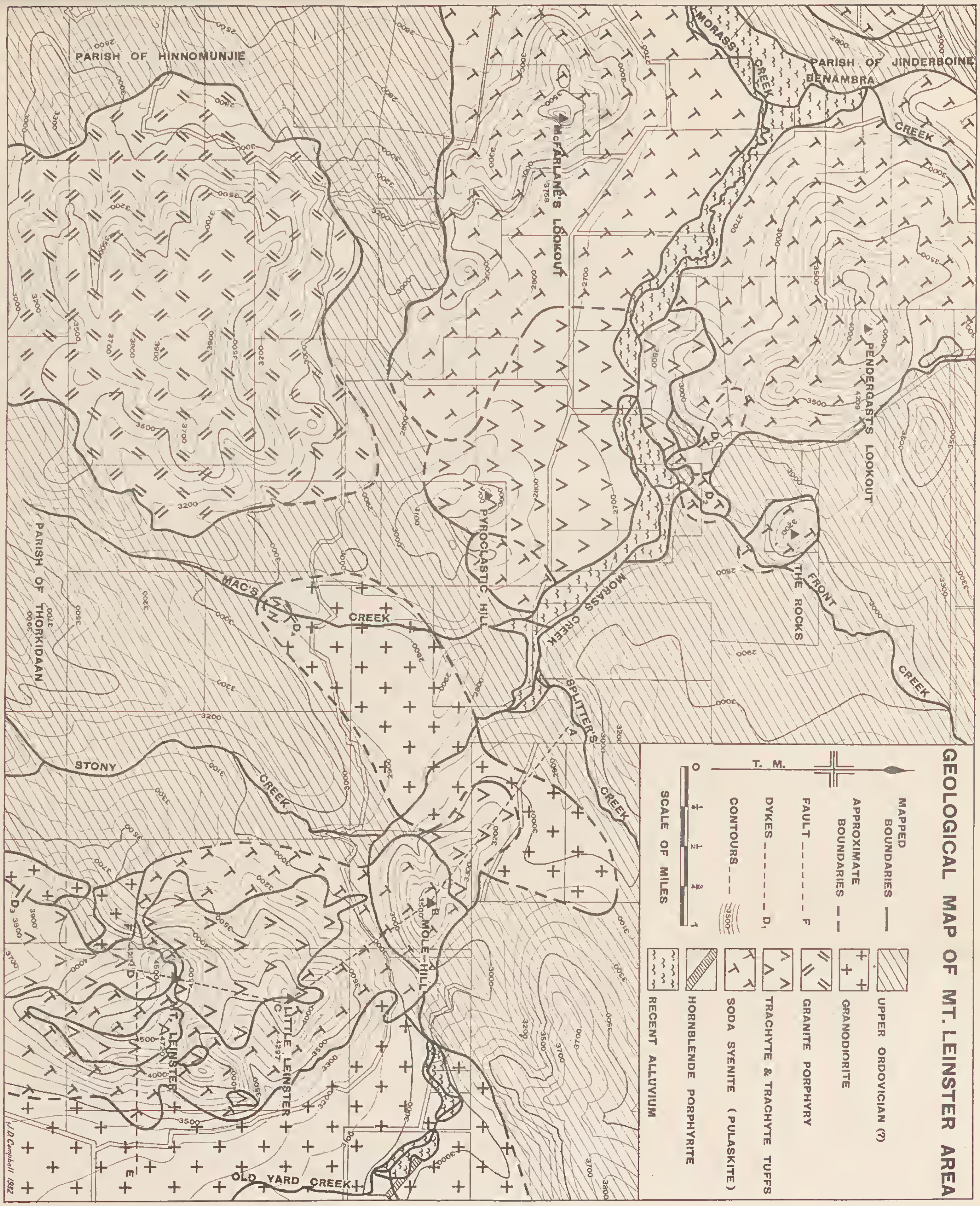

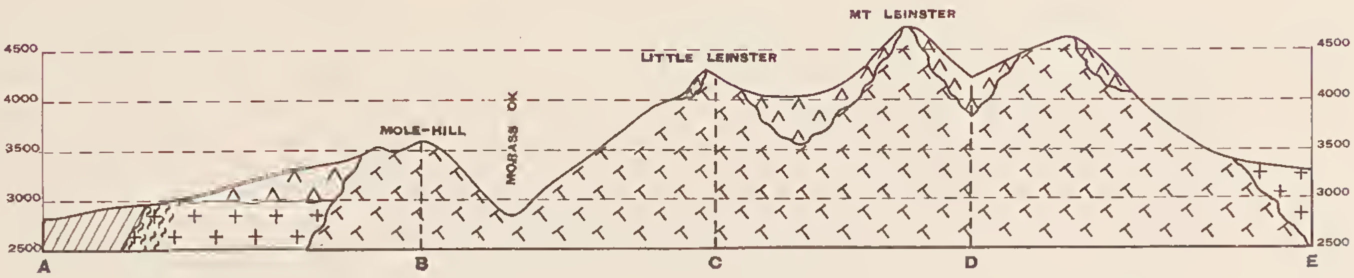

Fig. 3.—Sketch section along the line A B C D E, using the same geological symbols as in the map of the area